ONTARIO MUNICIPAL SEWAGE TREATMENT PLANTS MASS BALANCE PROJECT

Report - Metals

MISA ADVISORY COMMITTEE

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Introduction

The Ontario Ministry of Environment, Water Resources Branch, Water and Waste Water Management Section commissioned CANVIRO consultants to undertake a study of 37 municipal water pollution control plants in the Province. This pilot monitoring study has resulted in two reports; Volume I, Interim Report (1) and Volume II Appendix "A" (2) giving individual plant report data. They provide a first comprehensive indication of the loadings of metals and organics to these plants and the extent to which these substances are removed, sorbed to sludge, volatilized to the atmosphere, degraded or discharged in the effluent to the Province's receiving waters. It is understood that there is no intention to prepare interpretive reports.

The MISA Advisory Committee (MAC) however is interested in employing these data, to provide a perspective on the relative loadings of toxic contaminants from the municipal and the industrial sectors. MAC is also interested in ascertaining the effectiveness or efficiency of municipal sewage treatment plants (STPs) as a means of reducing the loading of these contaminants to the aquatic environment. STPs are primarily designed to remove the settleable and suspended solids and biodegradable material from sewage. Although they may be effective in removing metals and organic contaminants they are not primarily designed to do so. In view of the high capital costs of these installations, it is

important to develop options to major capital investments in improving STP removal efficiency. One option may be to increase the effectiveness of these plants for toxics removal by modifying and improving operating procedures. However another option that ultimately must be the most effective method of reducing loadings to the aquatic environment, is to restrict discharges to the sewer system, especially for those chemicals which will pass through the system, which cause sludge disposal problems, or which result in emissions to the atmosphere.

MAC has thus undertaken a preliminary study to estimate the mass balances and effluent loadings for the 37 STPs using the data published in the "Thirty Seven Municipal Water Pollution Control Plants, Pilot Monitoring Study, Volume I and Volume II (1988)." In the present assessment, emphasis is on metals which are regarded as the easiest of the contaminants to trace since they are not subject to evaporation or biodegradation. The plants included in the analysis and the nature of their processes are listed in Table 1. Attempts were made to compile mass balances for chromium, copper, mercury, cadmium, lead, nickel, aluminum, zinc and BOD.

The general aim of the study was to determine the metal loading to the plant in the raw sewage, the fraction removed in sludge and the residual that passes through to the effluent, the latter establishing the magnitude of the loading to the receiving water. A final aim was to ascertain metal removal efficiency according to plant type (primary, secondary or lagoon).

TABLE 1: SUMMARY OF MUNICIPAL TREATMENT PLANTS AND PROCESSES

STP	PLANT NAME	TYPE	PROCESS	SLUDGE TREATMENT
STP 1	Toronto (Main)	Secondary	Conventional activated sludge	Dissolved air flotation/ anaerobic digestion/elutriation/ vacuum filtration
STP 2	Hamilton (Woodward)	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion/ filter dewatering
STP 3	London (Greenway)	Secondary	Conventional activated sludge	Dissolved air flotation/ Belt press dewatering
STP 4	Niagara Falls (Stamford)	Secondary	Rotating biological contactors	Anaerobic digestion
STP 5	Ottawa (Green Creek)	Primary	Primary	Anaerobic digestion
STP 6	Sarnia	Primary	Primary	Anaerobic digestion
STP 7	Toronto (Highland Creek)	Secondary	Conventional activated sludge	Dissolved air flotation/anaerobic digestion/grinding/heat treatment/ centrifuge dewatering
STP 8	Waterloo	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion
STP 9	Windsor (Westerly)	Primary	Primary with polymer addition	Centrifuge dewatering/composting
STP 10	Belle River (Maidstone)	Secondary	Extended aeration	Aerobic digestion
STP 11	Burlington (Skyway)	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion
STP 12	Guelph	Tertiary	Conventional activated sludge plus RBC's plus filtration	Co-thickening/anaerobic digestion/ filter dewatering
STP 13	Kingston (Township)	Secondary	Conventional activated sludge	Anaerobic digestion
STP 14	Mississauga (Lakeview)	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion
STP 15	Sault Ste. Marie (East)	Primary	Primary	Vacuum filtration
STP 16	Thunder Bay	Primary	Primary	Anaerobic digestion
STP 17	Toronto (North)	Secondary	Conventional activated sludge	Anaerobic digestion/centrifuge dewatering

STP 18	Brantford	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion
STP 19	Cornwall	Primary	Primary	Anaerobic digestion/centrifuge dewatering
STP 20	Grimsby (Baker Road)	Secondary	Conventional activated sludge	Anaerobic digestion
STP 21	Kingston (City)	Primary	Primary	Anaerobic digestion (centrifuge dewatering)/storage
STP 22	Kitchener	Secondary	Conventional activated sludge	Anaerobic digestion
STP 23	London (Pottersburg)	Secondary	Conventional activated sludge	Co-thickening/storage
STP 24	Mississauga (Clarkson)	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion
STP 25	Moore (Corunna)	Secondary	Extended aeration	Holding tank, decanted
STP 26	Oakville (Southeast)	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion
STP 27	Paris	Secondary	Extended aeration	Aerobic digestion/thickening/storage
STP 28	Peterborough	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion+
STP 29	Pickering (Duffin Creek)	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion/+ filter dewatering
STP 30	Sault Ste. Marie (West)	Secondary	Conventional activated sludge	Co-thickening/filter dewatering
STP 31	Sudbury	Secondary	High rate	Anaerobic digestion
STP 32	Toronto (Humber)	Secondary	Conventional activated sludge	Dissolved air flotation/anaerobic digestion/elutriation/vacuum filtration
STP 33	Wallaceburg	Secondary	Conventional activated sludge	Anaerobic digestion/filter dewatering
STP 34	Windsor (Little River)	Secondary	Conventional activated sludge	Co-thickening/centrifuge dewatering
STP 35	Whitby (Pringle Creek #1)	Secondary	Conventional activated sludge	Co-thickening/anaerobic digestion
STP 36	Lindsay Lagoon	Lagoon	Aerated cells plus lagoon	No sludge production
STP 37	Niagara-on-the-lake Lagoon	Lagoon	Conventional lagoon	No sludge production

From: "Thirty Seven Municipal Water Pollution Control Plant, Pilot Monitoring Study, Volume 1, Interim Report, December 1988, pp. 37-39."

Data Analysis

Estimating the mass balance proves to be a difficult and imprecise task. In principle, the water flow in cubic meters per day (m^3/day) when multiplied by the concentration of the contaminants in grams per cubic meters (g/m^3) yields the loading of the chemical in grams per day (g/day). Water flow rates over the sampling period were averaged to estimate normal water flow into the plants. There is, however, uncertainty about water flow because it is variable and does not necessarily coincide with the time of sewage sampling. Similarly, there may also be high variability in the concentration of the chemical. The CANVIRO report generally records geometric means and percent frequency of detection. In some cases, data are missing. There are severe analytical problems in determining many of the chemicals at low concentrations especially in the presence of the complex matrix of the sewage.

The loading of chemical to the sludge can, in principle, be determined by multiplying the sludge production rate in kilograms per day (kg/day) by the concentration of chemical in the sludge, for example, in grams per kilogram (g/kg). Concentrations are given in milligrams of chemical per kilogram of dry sludge (mg/kg) but since no sludge flow rates are given, it is necessary to estimate these values which is extremely difficult. The approach taken here then is to calculate the metal loading to the plant, the metal loading in the effluent and by difference, estimate the metal loadings to the sludge for each metal and the average taken. The sludge concentration can then be used to estimate the flow rate of dry sludge per day. It must be emphasized that this calculation can be inaccurate because of lack of congruence between the

FIGURE 1: ILLUSTRATION OF MASS BALANCE CALCULATION

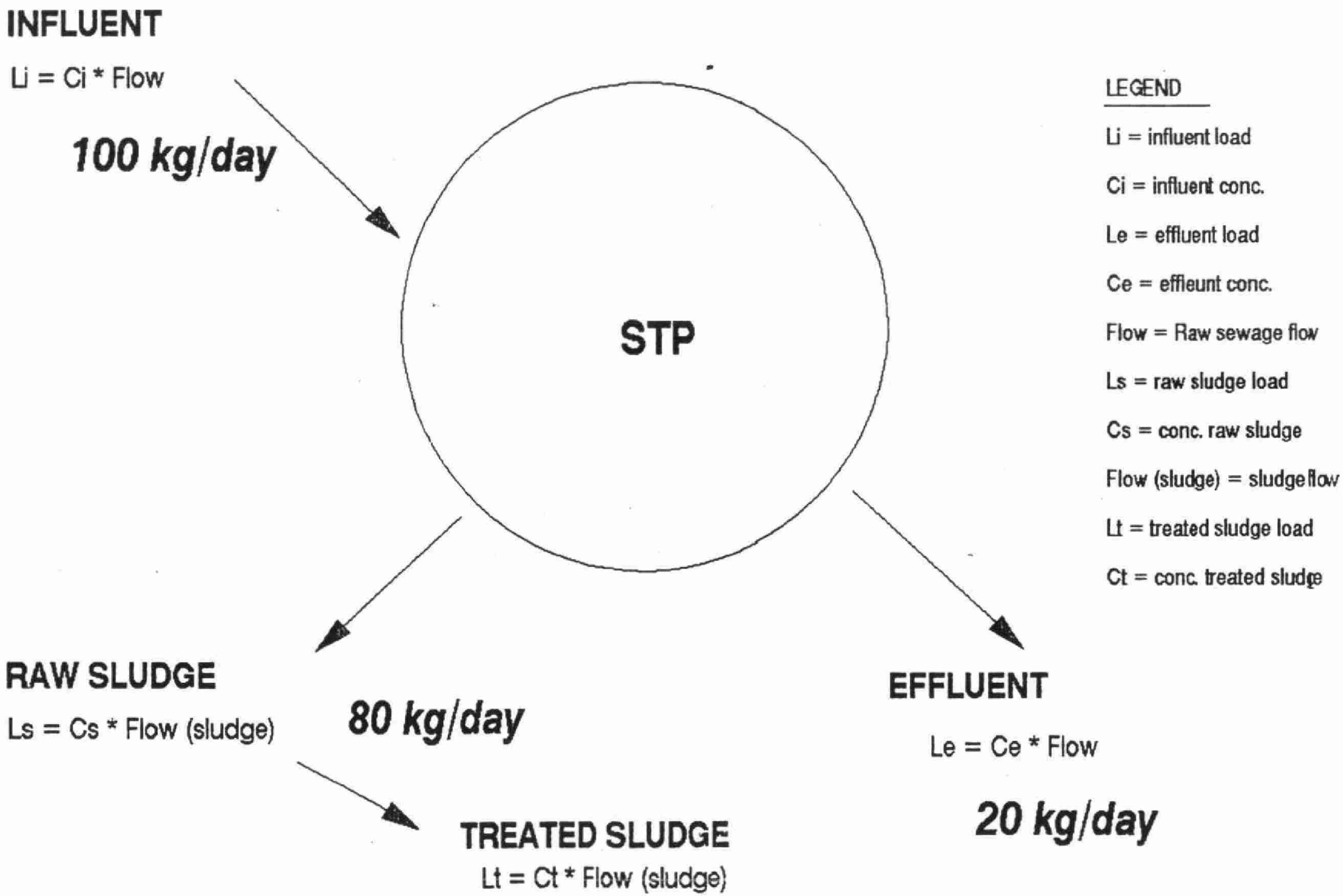

Table 2: Summary of Removal Efficiencies for Contaminants for each of the 37 STPs.

PERCENTAGE REMOVAL EFFICIENCY

CONTAMINANT	1	2	3	4	5′	6′	7	8	9′	10	11	12	13	14	15′	16′	17	18	19′
BOD	78	83	74	71	41	82	79	89	71	77	81	82	98	82	23	46	69	78	20
Cr	69	97	94	60	43	75	88	71	71	60	84	57		86		60	82	89	72
Cu	92		85	78	60	82	94	92	91		74	53		72	83	70	92	69	67
Hg	92	78	94	82	39	85	92	96	93	90	75	70	99	41	65	78	94	70	58
Cd		100	100	67			100	50	100		0	25		87				92	
Ni	63	65	-219		54		71	66	65		29	81		33			25	75	
Pb	89	74		70		78	62					-33				33			77
Zn	93	96	83	85	61	74	75	71	52	83	89	64	76	42	41	52	59	43	53
Al	95	98	93	92	63	85	-44	-14	82	8	78	35	97	93	-9	82	89	96	-62
Plant avg. (eff.)	84	86	51	76	52	80	68	65	78	64	64	48	92	67	41	60	73	77	41
Plant avg. (eff.-no Al)	82	86	44	73	50	79	82	77	78	77	62	50	91	63	53	57	70	74	58

CONTAMINANT	20	21′	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36L	37L	Contam.Avg
BOD	86	16	95	89	90	87	89	92	77	77	18	43	93	84	84	84	77	65	72
Cr		16	89	80	88	75		54	75	81		50	96	95	87	94			75
Cu			94	76	92		89	81		93		80	96	68	60			98	81
Hg	96	68	98	90	90	94	93	95	85	85	-6	83	97	87	91	84	83	93	81
Cd	ERR			100	67	100	100		100				96			89	100	100	83
Ni					29		37		0	33		10	45	42	42				32
Pb				75	91	71	0			83			81						61
Zn	91	-84	96	78	86	84	94	88	58	65	-52	20	93	63	62	74	91	80	64
Al	86		10	92	97	3	-1		92	92	37	82	87	80	71	96	75	86	61
Plant avg. (eff.)	90	4	80	85	81	73	63	82	70	76	-1	53	87	74	71	87	85	87	68
Plant avg. (eff.-no Al)	91	4	95	84	79	85	72	82	66	74	-13	48	87	73	71	85	88	87	69

**** ′ denotes primary plants
L denotes lagoons

concentration and flow rates, and the possibility that the effluent and sludge concentrations do not apply to the same stage in plant flow. (i.e. the time delay effect may not be taken into account).

Data from the CANVIRO reports were entered into a spreadsheet and mass balance calculations completed. The nature of the calculation is illustrated in Figure 1. Spreadsheet calculations are not presented here in detail but are available from the authors on request.

There is an additional difficulty in that sludge analyses reported are of both raw sludge and treated sludge. A problem arises in that the flow rates of raw or treated sludge become different for each contaminant in the same plant because of errors in analysis. To achieve consistency, the values estimated for aluminum were ignored because of the possibility of aluminum introduction as a treatment chemical in the plant. Mercury was ignored because the loadings were so small that the reported concentrations may be inaccurate. The calculated sludge flow values from the remaining metals were then assembled. All the calculated values were averaged for the remaining chemicals. This gave a reasonable estimate of the flow rate of sludge from the plant. Using this technique the data were assembled in several tables. Table 2 summarizes the removal efficiencies of the contaminants for each plant. As expected, removals are less in primary plants (plants offering sedimentation only) than in plants providing secondary treatment. Also percentage removals are highest where influent concentrations are highest and substantially lower where concentrations are dilute.

Finally effectiveness of removals is very dependent on actual loadings compared to design loadings. When plants are operating close to or over design capacity removal efficiencies are reduced. Data relating to conditions of loading were disclosed by the survey and are shown as plant capacity factors in Table 3.

The removal efficiencies for various metals vary considerably from plant to plant but it is clear that on average about 70% to 80% of the metal present in the sewage is removed in the sludge at secondary plants. Nickel is notable as a poorly-removed element, presumably because of its low tendency to sorb to biomass. The aluminum data may also be suspect because of analytical difficulties.

It can be concluded that the 37 STPs whether primary or secondary are efficient in removing a substantial fraction of the metal contaminants entering the system. Table 4 indicates the loadings of each contaminant to each sewage treatment plant (influent) and the total loadings to all 37 plants. Table 5 gives the loadings in the effluents in similar format and Table 6 sludge loadings.

These tables are valuable in that they provide an indication of the total loadings of metals from municipal plants to the aquatic environment. It is clear that substantial quantities of chromium, copper, lead, nickel and zinc are being discharged into surface waters. The amount of cadmium is fractionally much smaller and the high amount of aluminum may be the result of incorporation of natural mineral metals (e.g. clays in storm water as well as treatment chemicals).

TABLE 3: PLANT CAPACITY FACTORS FOR EACH OF THE 37 STPs

STP	PLANT NAME	PLANT CAPACITY FACTOR (%)
STP 1	Toronto (Main)	98
STP 2	Hamilton (Woodward)	70
STP 3	London (Greenway)	83
STP 4	Niagara Falls	83
STP 5	Ottawa (Green Creek)[1]	80
STP 6	Sarnia[1]	76
STP 7	Toronto (Highland Creek)	82
STP 8	Waterloo	96
STP 9	Windsor (Westerly)[1]	52
STP 10	Belle River (Maidstone)	87
STP 11	Burlington	78
STP 12	Guelph[3]	86
STP 13	Kingston (Township)	61
STP 14	Mississauga (Lakeview)	96
STP 15	Sault Ste. Marie (East)[1]	63
STP 16	Thunder Bay[1]	74
STP 17	Toronto (North)	79
STP 18	Brantford	65
STP 19	Cornwall[1]	135
STP 20	Grimsby (Baker Road)	68
STP 21	Kingston (City)[1]	83
STP 22	Kitchener	57
STP 23	London (Pottersburg)	63
STP 24	Mississauga (Clarkson)	74
STP 25	Moore (Corunna)	46
STP 26	Oakville (Southeast)	54
STP 27	Paris	37
STP 28	Peterborough	92
STP 29	Pickering (Duffin Creek)	99
STP 30	Sault Ste. Marie (West)	46
STP 31	Sudbury	71
STP 32	Toronto (Humber)	98
STP 33	Wallaceburg	100
STP 34	Windsor (Little River)	78
STP 35	Whitby (Pringle Creek #1)	47
STP 36	Lindsay Lagoon[2]	88
STP 37	Niagara-on-the-Lake Lagoon[2]	81

*** 1 denotes primary plants
2 denotes lagoons
3 denotes tertiary plants

Table 4: **Summary of Influent Loadings for contaminants for each sewage treatment plant .**

INFLUENT LOADING (KG/DAY)

CONTAMINANT	1	2	3	4	5′	6′	7	8	9′	10	11	12	13	14	15′	16′	17	18	19′
BOD	168890	57875	15682	4625	24871	6106	32573	5809	12627	234	16068	9418	5579	61028	3578	17601	3748	10228	4126
Cr	192	128	27	1	15	2	15	2	9	0.2	7	16		80		2	2	5	2
Cu	104	49	10	2	22	6	55	6	9	0.3	8	8	3	58	2	8	4	24	2
Hg	0.4	0.1	0.03	0.01	0.06	0.02	0.06	0.02	0.01	0.001	0.03	0.04	0.02	0.08	0.01	0.07	0.01	0.01	0.01
Cd	8	10	1	0.7		0.8	2	0.4	2		0.7	0.9	0.2	11				3	
Ni	76	33	8		28		15	3	18		3	10		67			0.7	39	
Pb	76	76		5		59	19				6	4				6			7
Zn	355	365	24	8	50	199	71	5	13	0.4	36	148	5	148	6	9	3	24	4
Al	2128	1723	280	83	152	91	363	62	599	3	175	125	312	595	18	137	20	126	106
Plant Total (no BOD)	2939	2383	351	101	268	358	540	77	650	4	236	312	320	960	26	162	31	222	120
Plant Total (no BOD,Al)	811	661	71	17	115	266	177	15	51	0.8	61	187	8	364	8	26	10	96	14

CONTAMINANT	20	21′	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36L	37L	Contam.Tot.
BOD	1990	3222	30653	2927	16861	651	1842	818	6407	26775	581	4350	158658	512	5350	623	1108	333	724330
Cr	0.1	2	13	0.7	10	0.1	0.5	0.1	4	49		1	115	4	2	1	0.5		708
Cu			13	1	10	0.2	1	0.2		63	0.4	2	113	4	1	0.4	0.8	2	593
Hg	0.004	0.01	0.05	0.002	0.04	0.000	0.002	0.001	0.01	0.06	0.001	0.013	0.3	0.001	0.005	0.001	0.001	0.000	1
Cd	0			0.2	1	0.03	0.1	0.03	0.9		0.08	1	54			0.1	0.3	0.09	99
Ni					3		0.5		2	42		5	81	7	2				441
Pb	1		9	2	27	0.2	1		11	33			64				5		409
Zn	5	2	77	2	45	0.5	8	0.4	10	56	1	4	572	1	7	0.4	3	0.2	2266
Al	6		134	18	212	2	15	3	53	653	10	22	785	5	45	21	13	3	9099
Plant Total (no BOD)	13	3	246	24	307	3	26	3	80	897	12	35	1784	21	57	22	22	5	13618
Plant Total (no BOD,Al)	7	3	111	6	96	1	11	0.7	27	244	2	13	999	16	12	2	9	2	4518

•••• ′ denotes primary plants
L denotes lagoons

Table 5: Summary of Effluent Loadings for contaminants for each sewage treatment plant.

EFFLUENT LOADING (KG/DAY)

CONTAMINANT	1	2	3	4	5′	6′	7	8	9′	10	11	12	13	14	15′	16′	17	18	19′
BOD	36932	9791	4140	1349	14635	1100	6872	661	3646	54	3061	1702	139	11159	2753	9474	1145	2241	3282
Cr	60	4	2	0.5	9	0.5	2	0.4	3	0.06	1	7		11		0.8	0.4	0.5	0.5
Cu	8		2	0.5	9	1	4	0.4	0.8		2	4		16	0.3	2	0.4	8	0.5
Hg	0.03	0.02	0.002	0.002	0.04	0.004	0.004	0.001	0.001	0.000	0.01	0.01	0.000	0.05	0.003	0.02	0.001	0.004	0.003
Cd		0.00	0.00	0.24	0.00		0.0	0.2	0.0		0.7	0.7		1		0.8		0.3	0.3
Ni	28	11	26	1	13	0.5	4	0.9	6	0.1	2	2		45			0.5	10	0.8
Pb	8	20	4	1	17	13	7	1	3			6		7		4	1	2	2
Zn	24	13	4	1	20	53	18	1	6	0.06	4	53	1	86	4	4	1	14	2
Al	104	32	18	7	57	14	524	71	109	3	39	81	9	42	19	25	2	5	172
Plant Total (No BOD)	232	80	55	12	124	82	559	76	128	3	49	153	10	208	23	38	6	38	177
Plant Total (no BOD,Al)	128	49	37	5	68	68	35	5	19	0.2	10	72	1	166	4	13	4	33	5

CONTAMINANT	20	21′	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36L	37L	Contam.Tot
BOD	272	2721	1636	316	1734	83	205	66	1467	6241	478	2496	11094	80	854	102	257	116	144355
Cr		1	1	0.1	1	0.02		0.03	0.9	9	0.08	0.5	4	0.2	0.3	0.06		0.03	121
Cu		3	0.7	0.3	0.8		0.1	0.03	2	5		0.5	4	1	0.6			0.03	76
Hg	0.000	0.004	0.001	0.000	0.004	0.00003	0.0002	0.00004	0.002	0.008	0.0008	0.002	0.008	0.0001	0.0005	0.0002	0.0002	0.00003	0.2
Cd	0.0	0.3	0.4	0.0	0.4	0.0	0.0		0.0	0.9			2		0.00	0.02	0.00	0.00	9
Ni			2	0.2	2	0.04	0.3		2	28		4	44	4	1	0.05	0.2	0.09	240
Pb				0.4	2	0.06				6			12	0.3	3	0.1			119
Zn	0.50	3	3	0.5	6	0.08	0.5	0.06	4	20	2	3	40	0.4	3	0.1	0.2	0.05	394
Al	0.8	30	121	1	6	2	15		4	52	6	4	99	1	13	0.8	3	0.4	1693
Plant Total (No BOD)	1	37	128	3	20	2	16	0.1	13	120	8	12	205	7	20	1	4	0.6	2651
Plant Total (no BOD,Al)	0.5	8	7	2	13	0.2	0.9	0.1	9	68	2	8	107	6	7	0.3	0.4	0.2	959

′ denotes primary plants
L denotes lagoons

Table 6: Summary of Contaminant Loadings to Sludge for each sewage treatment plant.

AMOUNT REMOVED TO SLUDGE (KG/DAY)

CONTAMINANT	1	2	3	4	5′	6′	7	8	9′	10	11	12	13	14	15′	16′	17	18	19′
BOD	131958	48084	11543	3277	10236	5006	25702	5147	8981	180	13007	7715	5441	49869	825	8127	2604	7987	843
Cr	132	123	26	1	7	2	13	1	6	0.09	6	9		69		1	2	5	1
Cu	96		9	2	13	5	52	5	8		6	4		42	2	6	4	17	1
Hg	0.4	0.09	0.03	0.01	0.02	0.02	0.05	0.02	0.01	0.001	0.02	0.03	0.02	0.03	0.01	0.06	0.01	0.009	0.004
Cd		10	1	0.5			2	0.2	2		0.00	0.2		10		0.8		3	0.3
Ni	48	22	-18		15		11	2	12		0.7	8		22			0.2	29	
Pb	68	56		3		46	12					-1				2			5
Zn	331	352	20	7	30	146	53	3	7	0.3	32	95	4	63	3	5	2	10	2
Al	2024	1691	262	77	96	77	-161	-9	490	0.2	136	44	303	553	-2	112	18	121	-65
Plant Total (no BOD)	2699	2254	299	90	161	276	-19	3	525	0.6	181	159	307	758	3	126	26	185	-56
Plant Total (no BOD,Al)	675	563	38	13	65	199	142	12	35	0.4	45	115	4	205	4	15	8	64	10

CONTAMINANT	20	21′	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36L	37L	Contam.Tot
BOD	1718	501	29017	2611	15127	568	1638	751	4940	20534	103	1854	147564	431	4497	520	852	217	579975
Cr		0.3	12	0.6	8.84	0.06		0.04	3	40		0.5	111	4	2	0.9			586
Cu			12	0.9	9.24		1	0.1		59		2	109	3	0.9			1.61	469
Hg	0.003	0.009	0.05	0.002	0.03	0.0005	0.002	0.0008	0.01	0.05	-0.00004	0.01	0.3	0.0007	0.005	0.0009	0.001	0.0004	1
Cd	0.00	0.3		0.2	0.8	0.03	0.1		0.9	0.9			52		0.00	0.1	0.30	0.09	85
Ni					0.8		0.2		0.0	14		0.5	36	3	0.7				206
Pb				1	24	0.2				27			52						296
Zn	5	-1	74	2	39	0.4	7	0.4	6	36	-0.5	0.7	532	0.6	4	0.3	2	0.2	1872
Al	5		14	17	205	0.06	-0.1		48	601	4	18	687	4	32	20	10	2	7434
Plant Total (no BOD)	10	-0.8	111	21	287	0.7	8	0.6	58	778	3	22	1579	14	40	21	12	4	10950
Plant Total (no BOD,Al)	5	-0.8	98	5	82	0.6	9	0.6	9	177	-0.5	4	892	10	8	1	3	2	3516

**** ′ denotes primary plants
L denotes lagoons

It is interesting to speculate on the probable total loadings of metals from all 412 STPs in Ontario. The 37 plants considered here have a total 1987 flow of 3.6 million cubic meters per day. As the total design flow of 412 plants is over 6 million cubic meters per day (m^3/day) and the total flow for 1987 was 5 million cubic meters per day (m^3/day), those 37 plants represent 72% of the total municipal flow in 1987. Pro-rating the metal loading data to 412 plants, i.e. increasing the loadings by a factor of 100 divided by 72, gives the loadings in Table 7. These loadings should be regarded as only very approximate estimates of the total metal burden reaching sewage treatment plants, entering sludge and entering receiving waters. These data are interesting in that they provide a first indication of the importance of STPs as sources of these contaminants and can be used to compare the relative importance of the municipal sector with other sectors when controlling toxic discharges under MISA.

Plant Type:

An analysis was also done of differences in performance as a function of plant type. Again it is stressed that the analysis is approximate. Of the 37 sewage treatment plants studied, 7 were primary plants, 26 were secondary, 1 was tertiary and 2 were lagoons. Table 8 lists the STPs according to plant type. The tertiary plant, STP 12 (Guelph) was grouped with the secondary plants to simplify the calculations. Table 9 summarizes the mean, maximum and minimum influent, effluent, sludge loadings and removal efficiencies for each contaminant for primary plants. Similarly, Tables 10 and 11 gives the mean,

TABLE 7: PRO-RATED METAL LOADINGS OF 37 STPs

37 STP TOTAL LOADING	influent (kg/day)	effluent (kg/day)	amt.removed (kg/day)
BOD	724330	144355	579975
Cr	708	121	586
Cu	593	76	469
Hg	1.5	0.2	1.3
Cd	99	9	83
Ni	441	240	206
Pb	409	119	296
Zn	2266	394	1872
Al	9099	1693	7434
Total (no BOD)	13618	2651	10947
Total (no BOD,Al)	4518	959	3513

PRO-RATED VALUES FOR TOTAL ONTARIO STP LOADINGS	influent (kg/day)	effluent (kg/day)	amt.removed (kg/day)
BOD	1006013	200493	805520
Cr	984	168	814
Cu	824	105	651
Hg	2.1	0.3	1.8
Cd	137	12	115
Ni	612	333	286
Pb	569	166	411
Zn	3148	547	2600
Al	12638	2351	10325
Ont.Total (no BOD)	18913	3682	15205
Ont.Total (no BOD,Al)	6275	1331	4880

TABLE 8: CLASSIFICATION OF STPs ACCORDING TO PLANT TYPE AND FLOW RATES

		Sample Flow (m^3/day)	1987 Flow (m^3/day)	Design Flow (m^3/day)
Primary STPs:				
STP5	Ottawa (Green Creek)	435571	400250	545000
STP6	Sarnia	53398	54000	70470
STP9	Windsor (Westerly)	84400	123640	163650
STP15	Sault Ste. Marie (East)	34371	32020	54550
STP16	Thunder Bay	81110	81110	109110
STP19	Cornwall	50497	43680	37500
STP21	Kingston (City)	52735	61370	63480
Secondary STPs:				
STP1	Toronto (Main)	798536	767200	818300
STP2	Hamilton (Woodward)	287130	306470	409140
STP3	London (Greenway)	101833	110800	122700
STP4	Niagara Falls (Stamford)	48256	-	58200
STP7	Toronto (Highland Creek)	178484	170000	218210
STP8	Waterloo	43511	46380	45460
STP10	Belle River (Maidstone)	5941	5600	6820
STP11	Burlington (Skyway)	72806	67030	93190
STP12	Guelph (note: tertiary plant)	47017	42430	54550
STP13	Kingston (Township)	15223	18030	25000
STP14	Mississauga (Lakeview)	271840	256900	284130
STP17	Toronto (North)	35886	36650	45460
STP18	Brantford	53552	52100	81830
STP20	Grimsby (Baker Road)	12376	13050	18180
STP22	Kitchener	69778	70580	122700
STP23	London (Pottersburg)	13937	16330	22050
STP24	Mississauga (Clarkson)	80292	74700	109100
STP25	Moore (Corunna)	2064	2180	4460
STP26	Oakville (Southeast)	12283	13520	22730
STP27	Paris	2600	2520	7050
STP28	Peterborough	62877	50790	68190
STP29	Pickering (Duffin Creek)	186587	176000	189250
STP30	Sault Ste. Marie (West)	8420	6650	18180
STP31	Sudbury	48094	48970	68190
STP32	Toronto (Humber)	402684	402700	409190
STP33	Wallaceburg	6848	6760	6820
STP34	Windsor (Little River)	28460	32760	36320
STP35	Whitby (Pringle Creek #1)	2650	3610	5680
Lagoons:				
STP36	Lindsay Lagoon	15046	14180	17180
STP37	Niagara-on-the-lake Lagoon	3089	6400	3800
	FLOW TOTAL	3710182	3617360	4435820

TABLE 9: SUMMARY OF PRIMARY STPs PLANT PERFORMANCE (n=7)

CONTAMINANT	INFLUENT (KG/DAY)			EFFLUENT (KG/DAY)			REMOVED (KG/DAY)			%REMOVAL EFF.		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
BOD	10304	4126	24871	5373	1100	14635	4931	501	10236	43	16	82
Cr	5	2	15	2	1	9	3	0.3	7	56	16	75
Cu	8	2	22	2	0	9	6	1	13	75	67	91
Hg	0.03	0.01	0.06	0.01	0.00	0.04	0.02	0.00	0.02	70	58	93
Cd	1.2	0.8	1.7	0.3	0.0	0.8	1.7	0.3	1.7	100	100	100 *
Ni	23	18	28	5	1	13	14	12	15	65	65	65 *
Pb	24	6	59	8	2	17	18	2	46	63	33	78
Zn	40	2	199	13	2	53	27	-1	146	36	-84	74
Al	184	18	599	61	14	172	118	-65	112	40	-62	85

* only 1 data value

TABLE 10: SUMMARY OF SECONDARY AND TERTIARY STPs PLANT PERFORMANCE (n = 27)

CONTAMINANT	INFLUENT (KG/DAY)			EFFLUENT (KG/DAY)			REMOVED (KG/DAY)			%REMOVAL EFF.		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
BOD	22335	234	168890	3853	54	36932	18482	103	147564	74	18	98
Cr	25	0.1	192	4	0.03	60	23	0.04	132	79	50	97
Cu	21	0.2	113	3	0.03	16	22	1	109	82	53	96
Hg	0.05	0.0005	0.41	0.01	0.0001	0.05	0.04	-0.00004	0.38	83	-6	99
Cd	4	0	54	0.36	0.00	2	5	0	52	80	0	100
Ni	22	0.5	81	9	0.0	44	10	-18	48	29	-219	81
Pb	22	0.2	76	4	0.1	20	24	-1	68	66	-33	91
Zn	71	0.4	572	11	0.1	86	60	-1	532	70	-52	96
Al	285	2.3	2128	47	0.8	524	249	-161	2024	65	-44	98

TABLE 11: SUMMARY OF LAGOON PLANT PERFORMANCE (n = 2)

CONTAMINANT	INFLUENT (KG/DAY)			EFFLUENT (KG/DAY)			REMOVED (KG/DAY)			%REMOVAL EFF.		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
BOD	721	333	1108	186	116	257	534	217	852	71	65	77
Cr	0.53	1	1	0.03	0.03	0.03						
Cu	1	1	2	0.03	0.03	0.03	2	2	2	98	98	98
Hg	0.0009	0.00041	0.0014	0.0001	0.00003	0.0002	0.0008	0.09	0.3	88	83	93
Cd	0.20	0.09	0.3	0	0	0	0.20			100	100	100
Ni				0.12	0.09	0.15						
Pb	5	5	5									
Zn	1	0.23	3	0.14	0.05	0.23	1	0.2	2	86	80	91
Al	8	3	13	2	0.4	3.2	6	2	10	81	75	86

maximum and minimum loadings and removal efficiencies for secondary plants and lagoons respectively. Mean BOD removal efficiency for secondary plants and lagoons is approximately 70% (Table 10 and 11) whereas for primary plants it is 43% (Table 9). Mean metal removal efficiencies range between 70 to 80% with the exception of nickel (29%) for secondary plants; between 70 to 95% for lagoons and between 30 to 70% for primary plants. For both BOD and metal removal efficiency, primary plants are of course significantly less effective in removal of contaminants. These comparisons demonstrate clearly the significant value achieved in increased metal removal by investing in the higher cost of secondary treatment over primary.

This analysis shows that a significant portion of the contaminants entering the three types of STPs, in particular primary plants, are released through their effluents to the province's waterways. In all cases, control of metals at the source will decrease the load on the STPs thereby reducing the concentration of metals in sewage sludge and ensuring improved control of metals entering the province's water resources.

An obvious sequel to the study is to examine the mass balance for organic chemicals. However, this is a much more difficult task because of the volatility and biodegradability of many of these chemicals. MAC believes, therefore, that a mass balance accounting based on metals is not only valuable but sufficient to show the relative need for controlling toxic discharges from municipal sources as compared with industrial sectors under MISA. It also demonstrates the need for the control of industrial discharges to municipal sewer systems.

Conclusions

An attempt has been made to compile a mass balance for metals from municipal sources using selected data from the 37 Plant Study with a view to establishing total loadings to sewer systems, to sludges and to the receiving waters and to indicate the relative importance of controlling toxics in municipal discharges to those from industrial sectors under MISA.

MAC invites, and encourages, discussion of this document and in particular, suggestions as to how the mass balance may be compiled with greater accuracy.

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